DETECTION OF NATURALLY OCCURRING EVENTS FROM SMALL APERTURE INFRASOUND ARRAYS

John M. Noble and Stephen M. Tenney

U.S. Army Research Laboratory
2800 Powder Mill Road, Adelphi, MD 20783

Phone:301-394-5663; FAX: 301-394-4797
Email: jnoble@arl.army.mil

Abstract

We report on data recorded from small aperture (20 m) infrasonic microphone arrays. These data include the well-observed Pennsylvania bolide of 7/23/01 and local severe storm passages. Data were obtained from two infrasonic arrays in southern Maryland. Analyzed results from two independent packages are presented, including bearing estimates and detector performance. Bolide detection results are correlated with eyewitness reports of the flight trajectory. Estimates are made of the bolide source energy from the application of the historical explosion scaling law relating the period at maximum acoustic amplitude. Finally, data from the passage of several severe storms are presented showing the detection and tracking of a low frequency acoustic signature of the storm including a category F4 tornado that struck La Plata, Maryland.

1 INTRODUCTION

ARL has operated an infrasonic array of microphones, with data collection, and signal processing operating as a server of infrasonic data since July 1998. The goal of this experiment is the study of all aspects of infrasonic signals in the atmosphere. Our interest began with the detection of impulsive signals like artillery, mortars, and missiles, but due to the nature of infrasonic propagation in the atmosphere we must also include other "background" signals that reach our sensors. By selecting array geometry with a 20 m spacing, we have directivity in a frequency range that is tactically useful to the Army (3 - 8 Hz). The study of the infrasonic energy available at these frequencies includes signatures of many natural events and man-made machines such as: thunderstorms, power stations, aircraft, and gas supply lines. Determination of the source of the signals detected by an infrasonic array has proven to be time consuming [1].

Detections have ranged from Space Shuttle launches to local power station noise. We have detected explosive testing from Dahlgren and Quantico in Virginia and Stump Neck in Maryland, as well as Concorde flights, after leaving Kennedy International Airport, accelerating over the Atlantic Ocean. This paper discusses the detections made during the operation of our infrasound arrays. The configuration of the arrays and the signal processing are described in a companion paper [2].

2 NATURAL SOURCES OF INFRASOUND

There are many naturally occurring sources of infrasound. These sources include severe thunderstorms, tornadoes, microbaroms, bolides, volcanoes, auroras, avalanches, etc. Table 1 gives frequencies and pressure levels for a number of natural sources [3].

Table 1: Natural sources of infrasound.

Source	Period (s)	Frequency (Hz)	Sound Level (Pa)
Tornadoes	0.1 – 50	0.02 – 10	0.05 – 0.3 Pa at 30 – 800 km
Mountain associated waves	10 – 50	0.02 – 0.1	0.1 – 3 Pa
Strong earthquakes	8 – 30	0.03 – 0.12	0.1 – 2 Pa at 100 - 1000 km
Volcanic eruptions	> 100	< 0.01	15 Pa at some 1000 km
Snow avalanches	0.5 - 2	0.05 – 2	0.02 – 0.05 Pa at 100 km
Meteorites	0.2 – 18	0.05 - 5	0.05 – 1 Pa at 100 - 1000 km
Aurora	10 – 1000	0.001 – 0.1	0.1 – 0.5 Pa
Microbaroms	2 – 8	0.12 – 0.5	0.01 – 1 Pa

The mechanisms that generate the infrasound from many of these sources are not well understood. Many of these sources have been measured over the years by University of Alaska, Los Alamos National Laboratory, and other groups involved in the worldwide Infrasound Monitoring Stations (IMS) in support of the nuclear explosion monitoring.

3 DETECTIONS

We have collected data on some of the natural events such as tornadoes, severe storms, and meteorites. Figure 1 shows the first severe thunderstorm to pass our array in southern Maryland. The upper left image is the average coherence across the array with time. The left middle image is the bearing to the source with time. The bottom left image is the phase velocity across the array. This is a crude estimation of the elevation of the source since the acoustic wave traveling along the ground will pass the array at the speed of sound and elevated signals will pass the array at higher speeds. A coherent signal begins around 15 minutes into the hour with an accompanying bearing to the west. Around 35 minutes into the hour the phase velocity begins to increase indicating the source is elevated. At 45 minutes into the hour, the wind speed increases to 20 mph causing the wind noise to increase at the microphones and masking the signal. After 5 minutes, the wind speed decreases allowing for reacquisition of the signal. The bearing to the signal has now changed to the east. This indicates that the strong segment of the storm has passed over the array and is moving away from the array to the east.

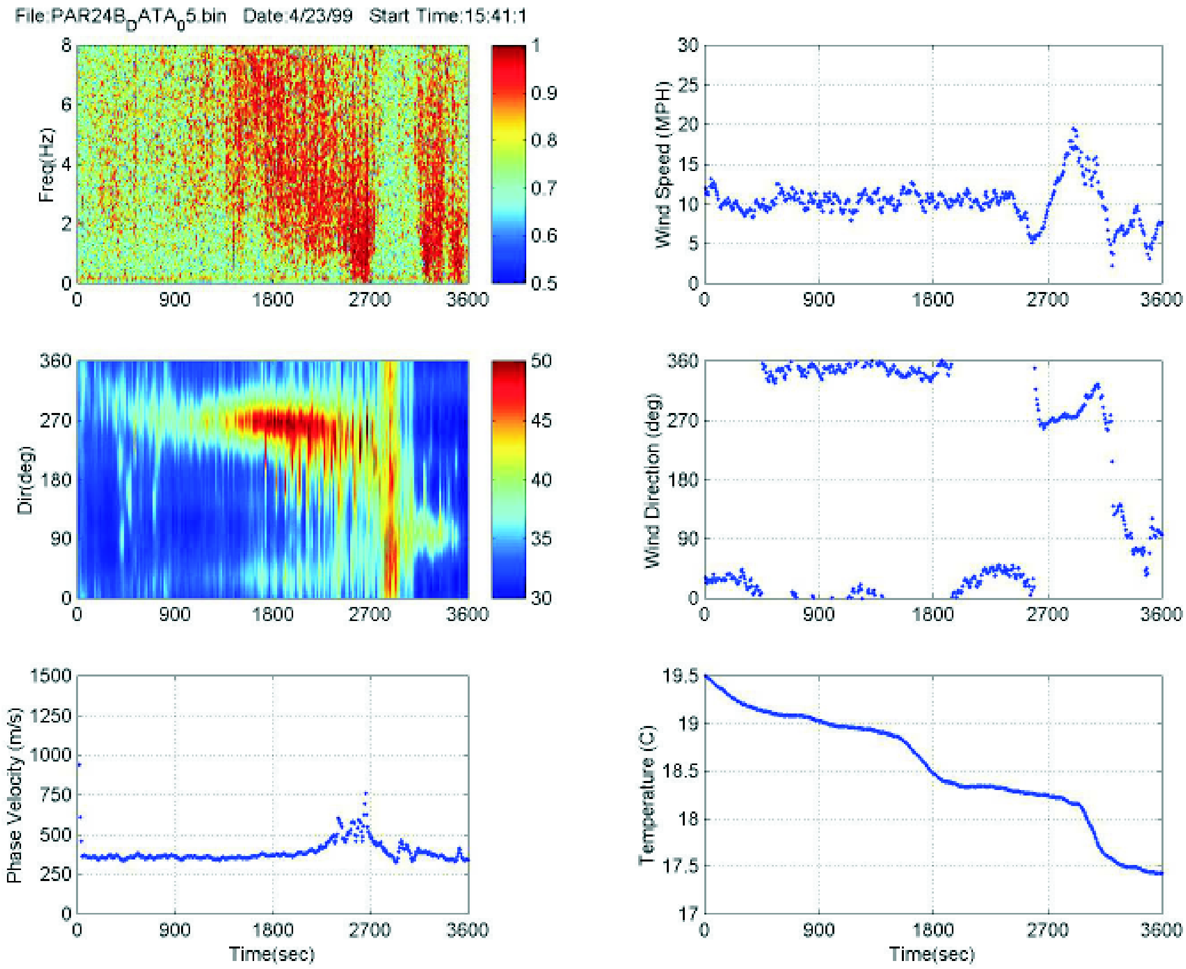

Figure 1: April 23, 1999 thunderstorm.

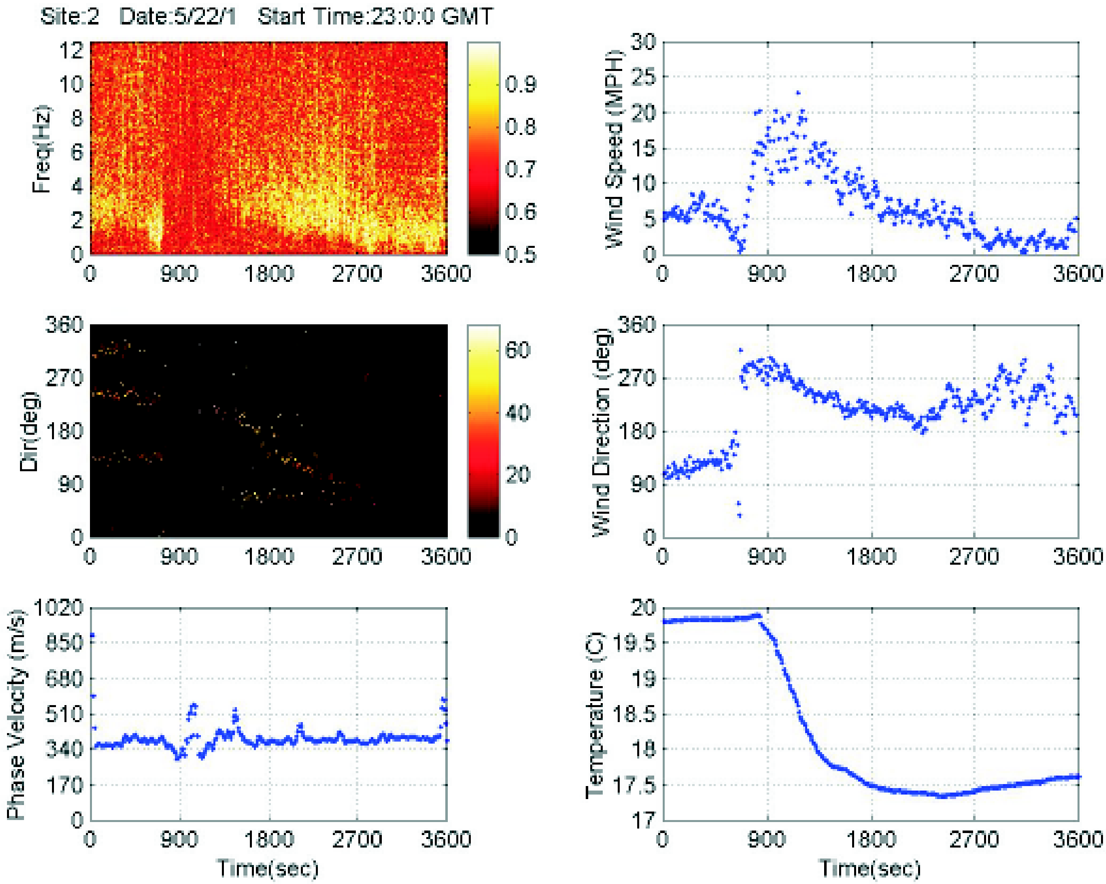

Figure 2: May 22, 2001 thunderstorm.

Figure 2 shows the passage of another severe storm on May 22, 2001. The first 15 minutes shows three different tracks indicating the array is tracking on three distinct areas of the storm that are generating sound. The coherence plot shows that most of the coherent energy is below 5 Hz. At 15 minutes into the hour, the wind increases to 20 mph causing a loss in the signal due to wind noise. The wind speed finally reduces enough to reacquire the signal about 5 minutes later. The tracks have changed from three to two tracks. Figure 3 shows the 2230 and 2330 UT Doppler radar images of the storms. Arrows indicate the location of the three closest strong storm cells from the array indicated by the reddish color in the radar reflection. As the storm front evolves to the 2330 UT Doppler radar image, the storm cells appear to merge into a single line with the array pointing to the strongest section of the storm front.

One of the most interesting weather events detected by the array was the F-4 tornado that hit La Plata, MD in April 28, 2002. Figure 4 shows the track of the tornado before and after it hit La Plata. The closest point to our array from the tornado was about 8 miles. Figure 5 shows the analyszed results from the infrasound array using MatSeis [5]. The start of a track is seen about 25 minutes into the hour, passing north of the array at 45 minutes into the hour, and is lost at about 50

Figure 3: The 2230 and 2330 UT Doppler radar images of the May 22, 2001 thunderstorm. The white dot indicates the array location. The arrows indicate the location of the strongest storm cells to the array.

minutes. A power spectrum of the time series during the tornado passage was calculated. Figure 6 shows the power spectrum and illustrates a series of peaks in the spectrum. The spectrum is calculated for the time segment before and after the tornado passage and the peaks do not appear in either of those segments. The questions is “do those peaks correspond to the tornado?” We have just finished a series of measurements on a number of tornadoes to study if the spectral peaks appear in other tornadoes.

Bolides also emit infrasound due to their passage through the atmosphere. We have measured two bolide events: July 23, 2001 and March 27, 2003. The January 23, 2001 bolide passed up the east coast and terminated over Pennsylvania. Figure 7 is a picture of the bolide. Analysis of the infrasound data, figure 8, during that time showed the passage of a very coherence source matching the time for the bolide passage. An estimate of source energy can be made from the empirical relation for explosions derived during the 1960s infrasonic monitoring program as given by [6]

$$E(kt) = 2\left(\frac{T}{5.92}\right)^{3.34} \qquad (1)$$

where E is the energy in kilotons (kt) and T is the acoustic period at maximum amplitude in seconds. For the July 23, 2001 bolide, T is 2.85 sec giving an energy estimate of 0.18 kt. This is a reasonable estimate but does not include effects, because the empirical relation was derived for low-altitude explosions. These estimates are important to compare the energy derived from the acoustic estimation to that from satellites. The source energy estimation from satellites can be skewed due to the type of material of which the bolide is composed.

The other bolide event was March 27, 2003. The entry point was south of Chicago, IL and the explosion was north of Chicago. Figure 9 shows the analysis of the acoustic energy received from the explosion of the bolide. This bolide explosion was also detected by an IMS array in Canada.

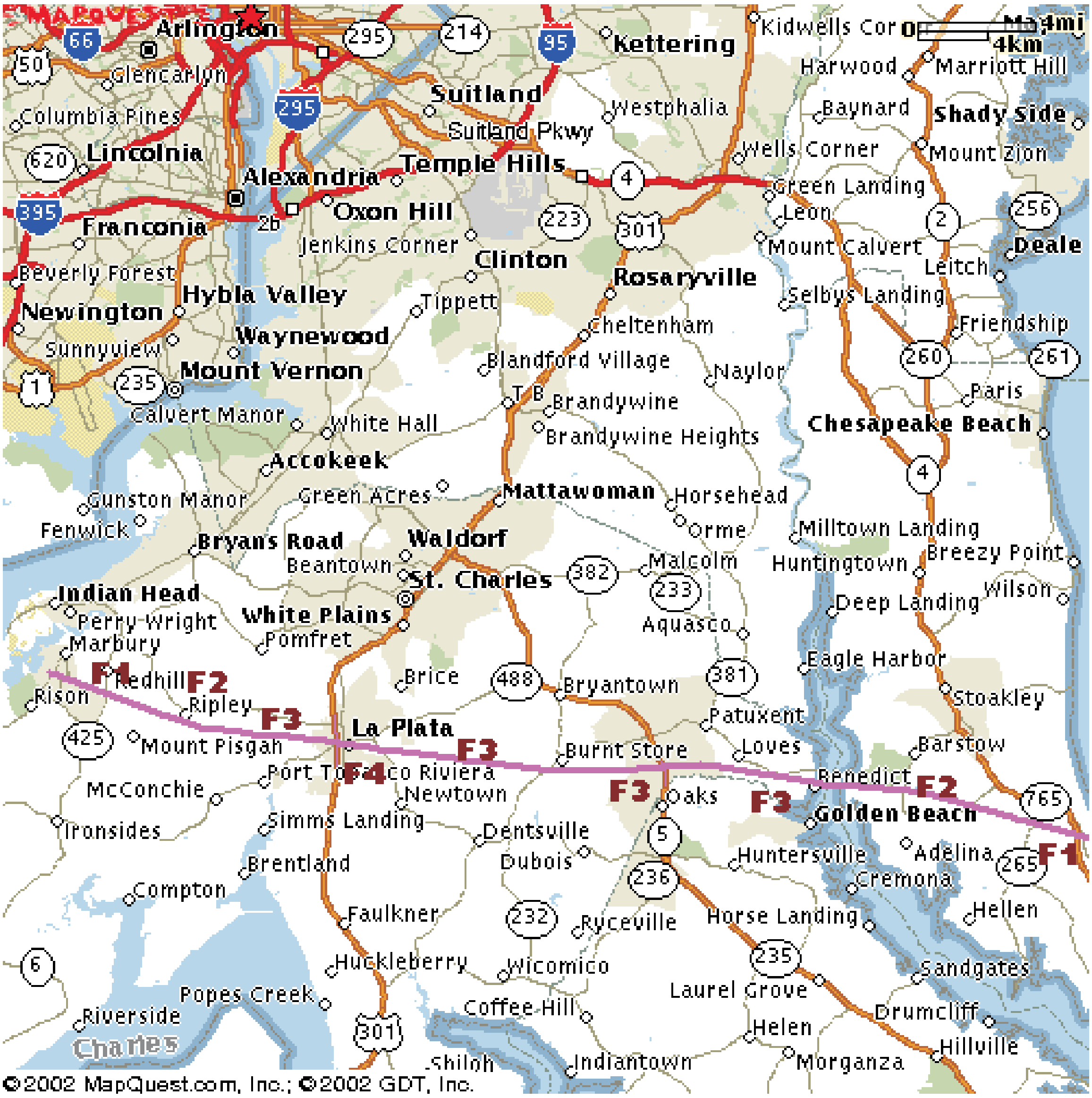

Figure 4: Track of the April 28, 2002 La Plata, MD tornado.

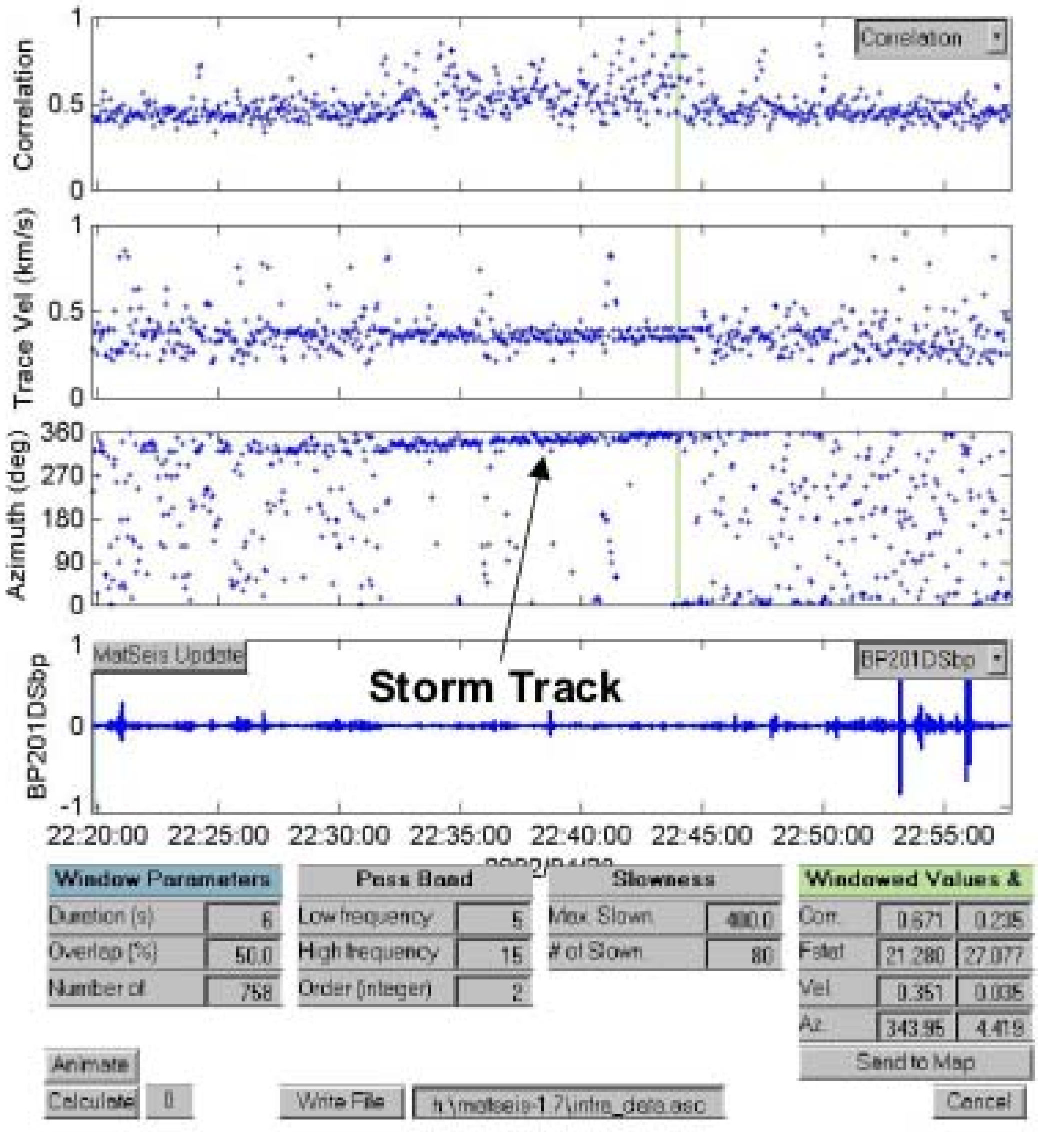

Figure 5: MatSeis analysis of the infrasound array data showing the track of the La Plata tornado.

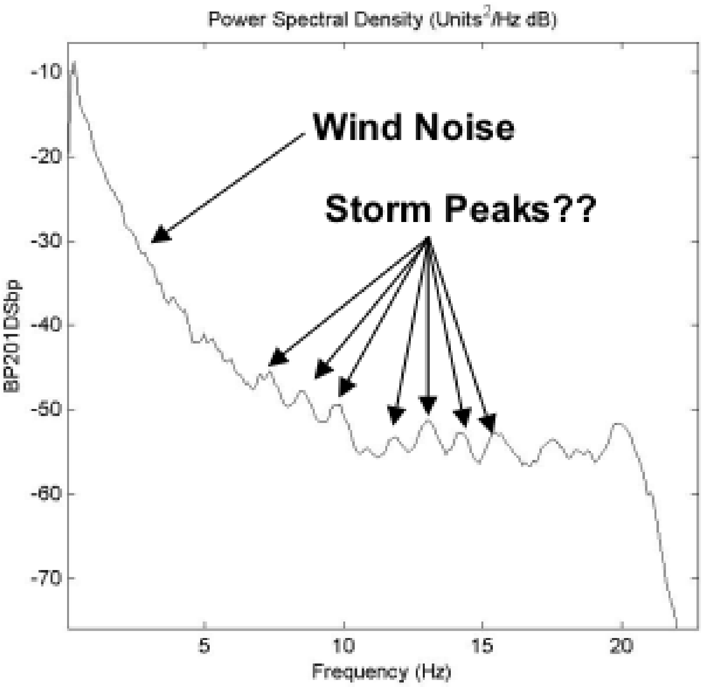

Figure 6: Power spectrum of the infrasound array data showing peaks for the La Plata tornado.

Figure 7: Picture of the July 23, 2001 bolide.

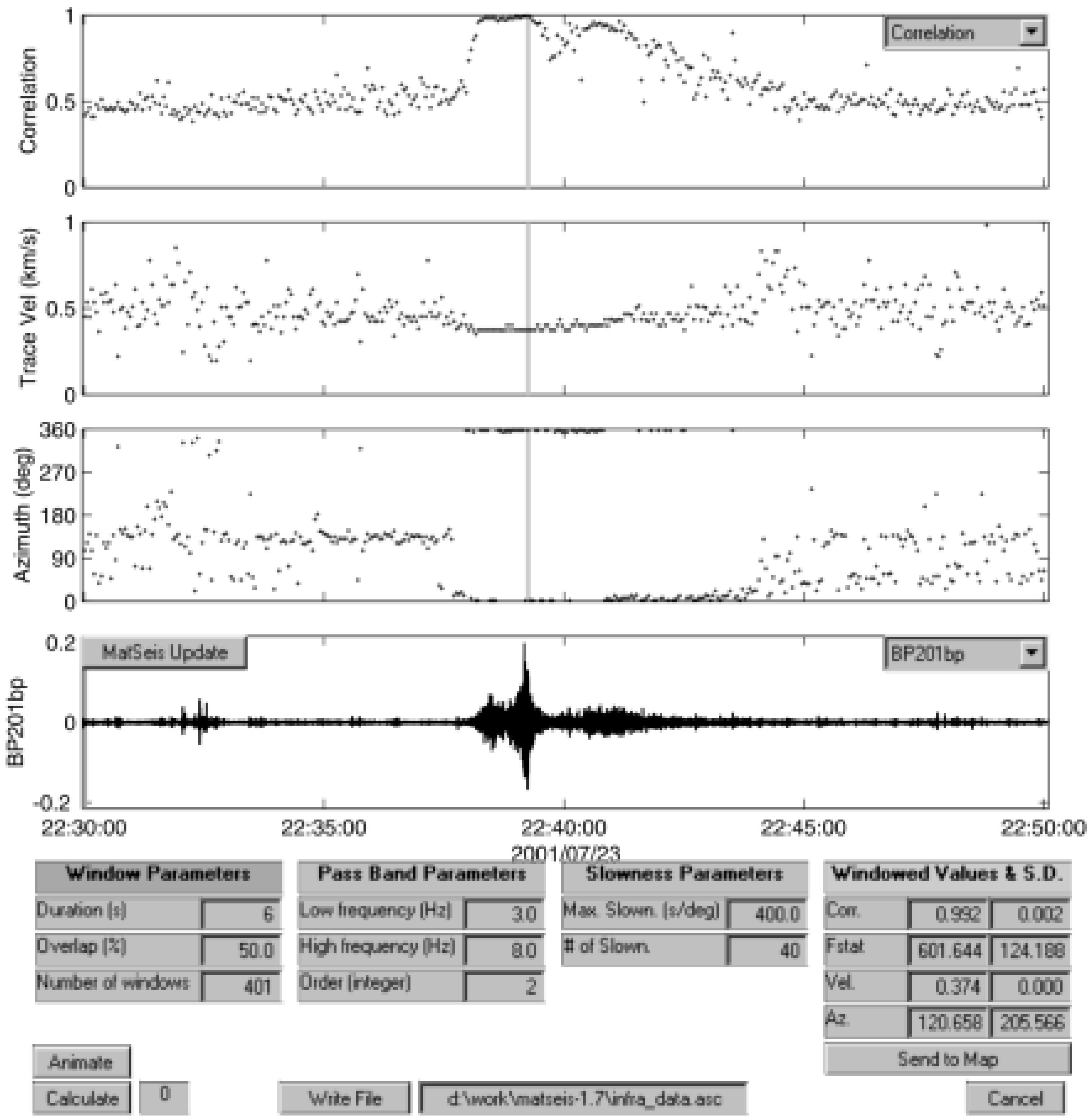

Figure 8: MatSeis analysis of the infrasound array data showing the track of the bolide passage on July 23, 2001.

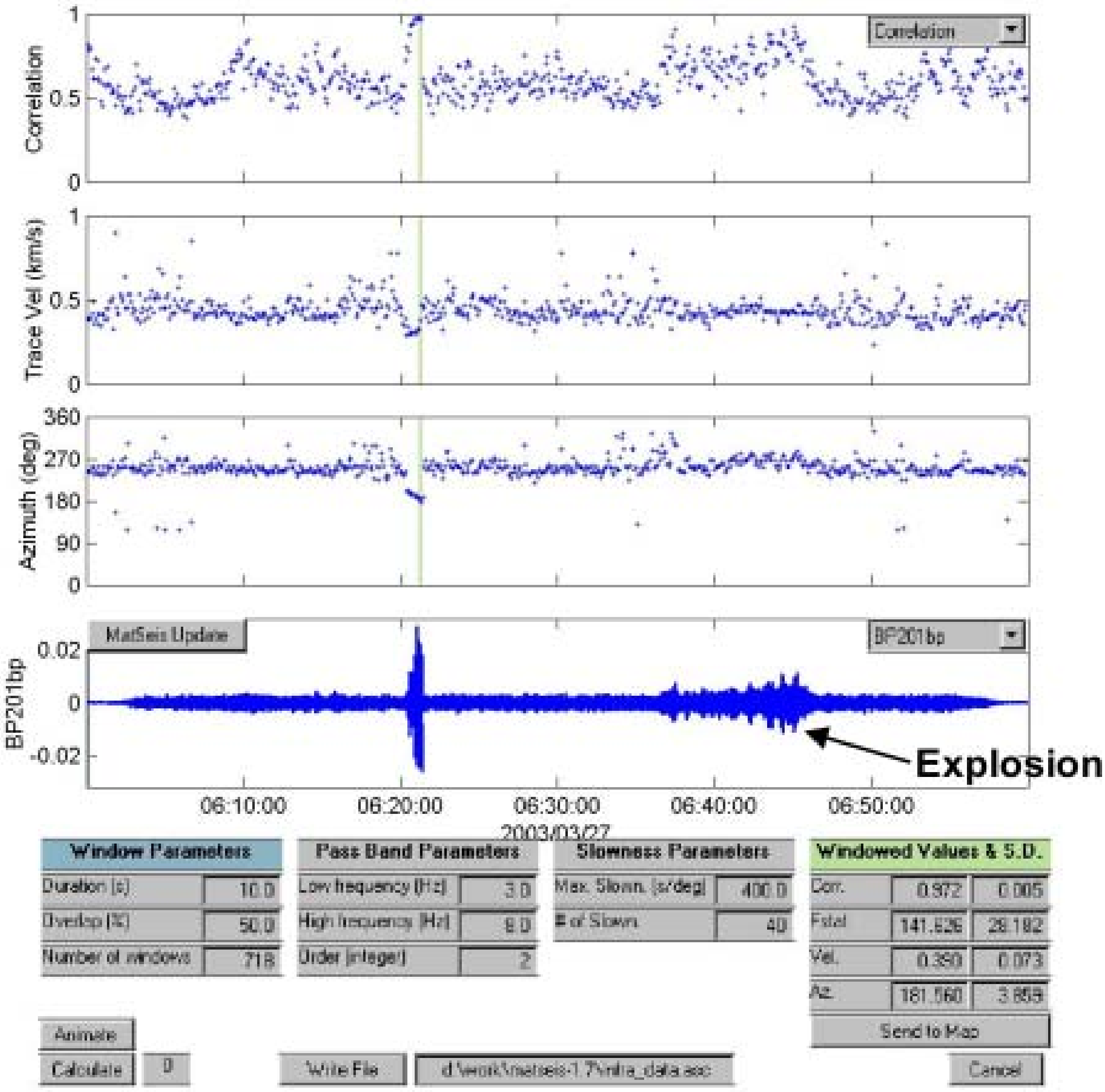

Figure 9: MatSeis analysis of the infrasound array data showing the track of the bolide passage on March 27, 2003.

4 CONCLUSIONS

Operation of the arrays has created a valuable source of infrasonic data for study and review. Understanding the infrasonic signatures created natural events provides the ability to filter these detections from more valuable man-made sources. Work is being conducted to develop a database of these natural infrasonic sources for use in identification algorithms. Studying the characteristics of natural sources will enhance the ability to minimize false detections due to their presence.

References

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